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(54) **HYBRID POWERTRAIN**

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F16H 48/30 (2006.01)
B60K 1/02 (2006.01)

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(58) **Field of Classification Search** 475/5, 150, 475/151; 477/3; 180/65.21, 65.225, 65.23, 180/65.235, 65.24
See application file for complete search history.

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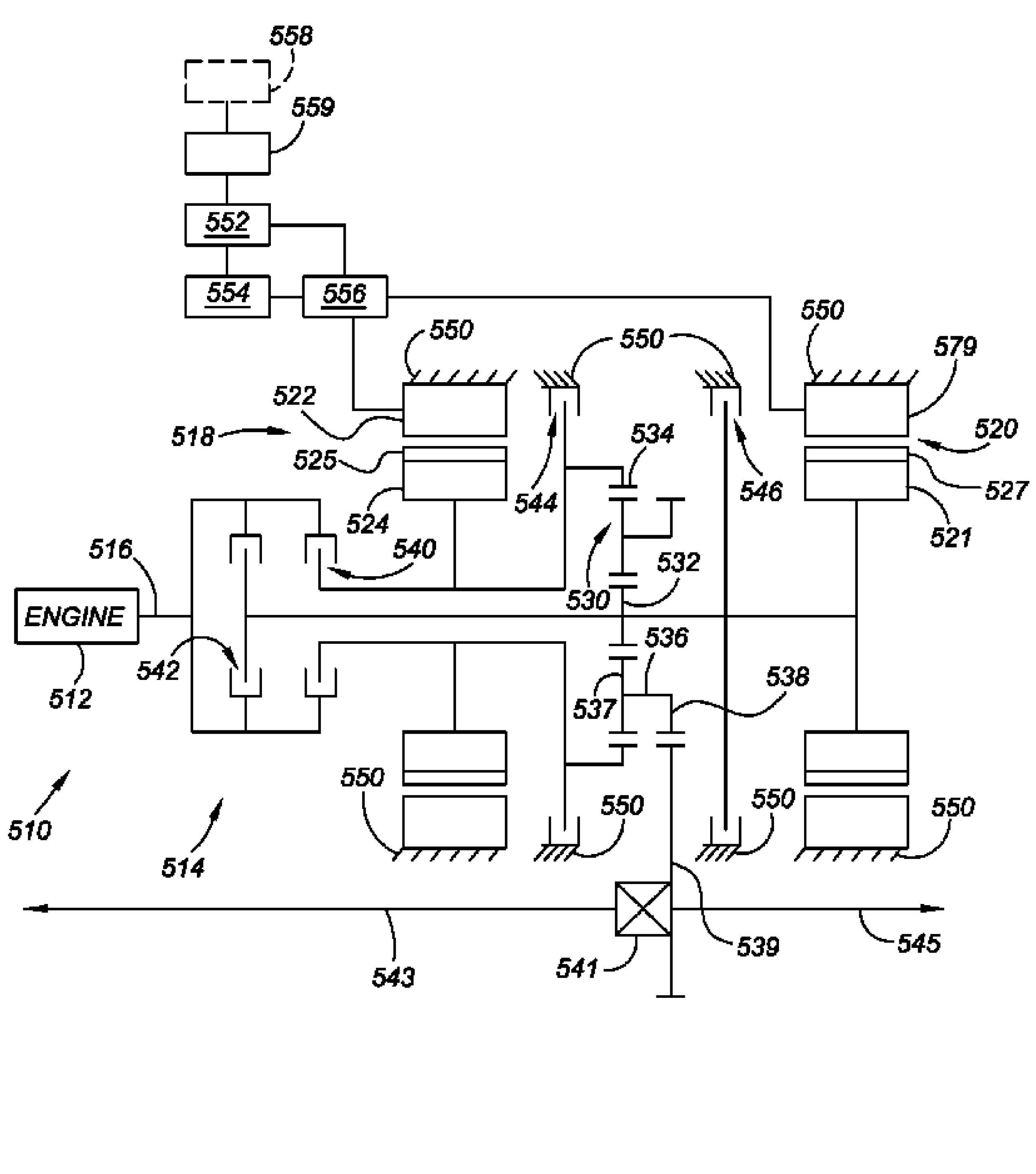
(57) **ABSTRACT**

A hybrid powertrain is provided that includes an engine operatively connected with an input member. The powertrain includes a transmission with first and second electric motor/generators, a differential gear set having multiple members, and selectively engagable torque-transmitting mechanisms. The input member, the output member, the engine and the motor/generators are selectively interconnected through the differential gear set by engagement of the torque-transmitting mechanisms in different combinations. An electronic controller controls the electric motor/generators, the engine and the torque-transmitting mechanisms to provide multiple operating modes between the input member and the output member, including an electric-only operating mode in which the engine is off and one motor generator acts as a motor to provide torque at the output member while the other electric motor/generator can remain substantially stationary, and another electric-only operating mode in which both electric motor/generators act as motors to provide torque at the output member.

17 Claims, 3 Drawing Sheets



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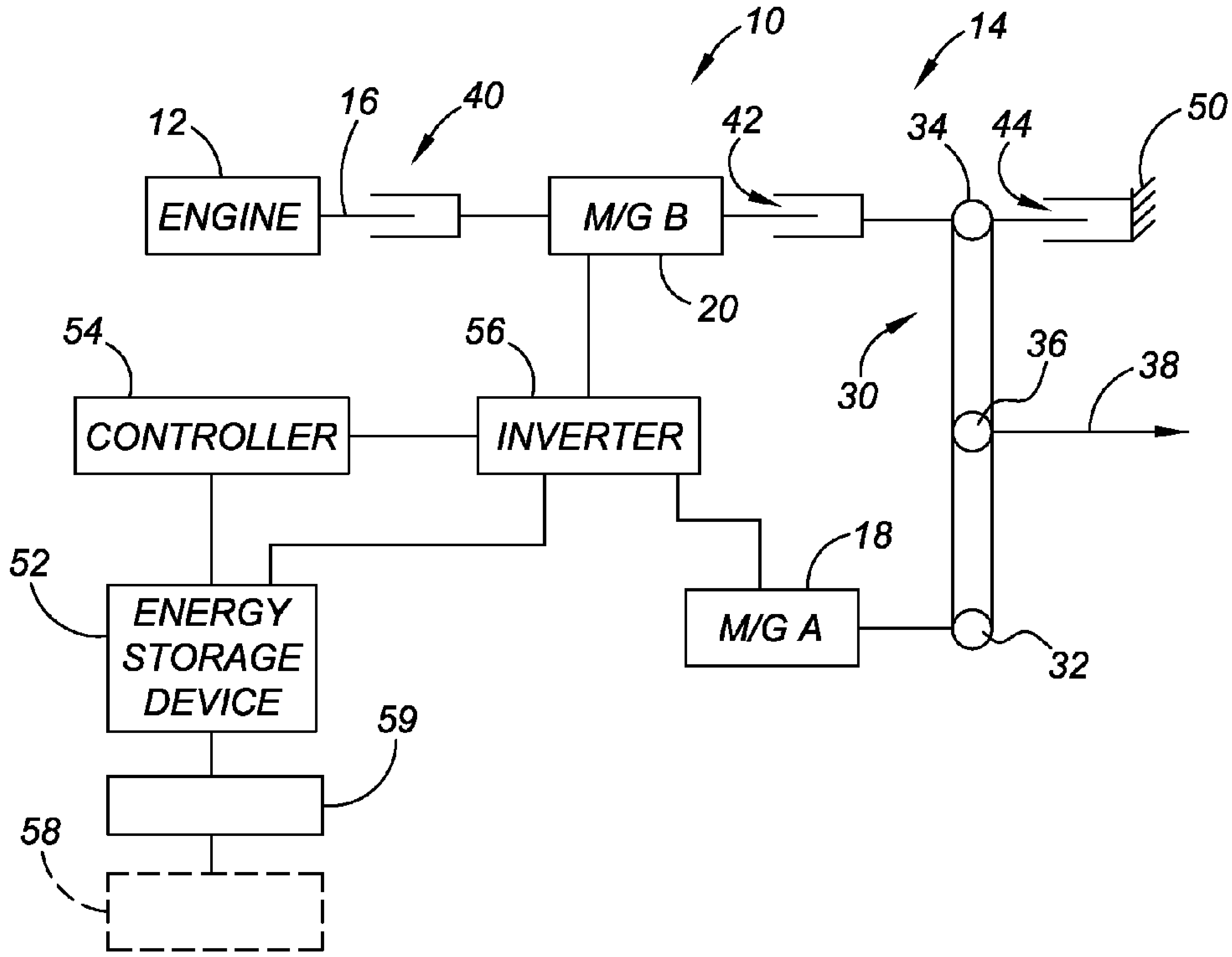


FIG. 1

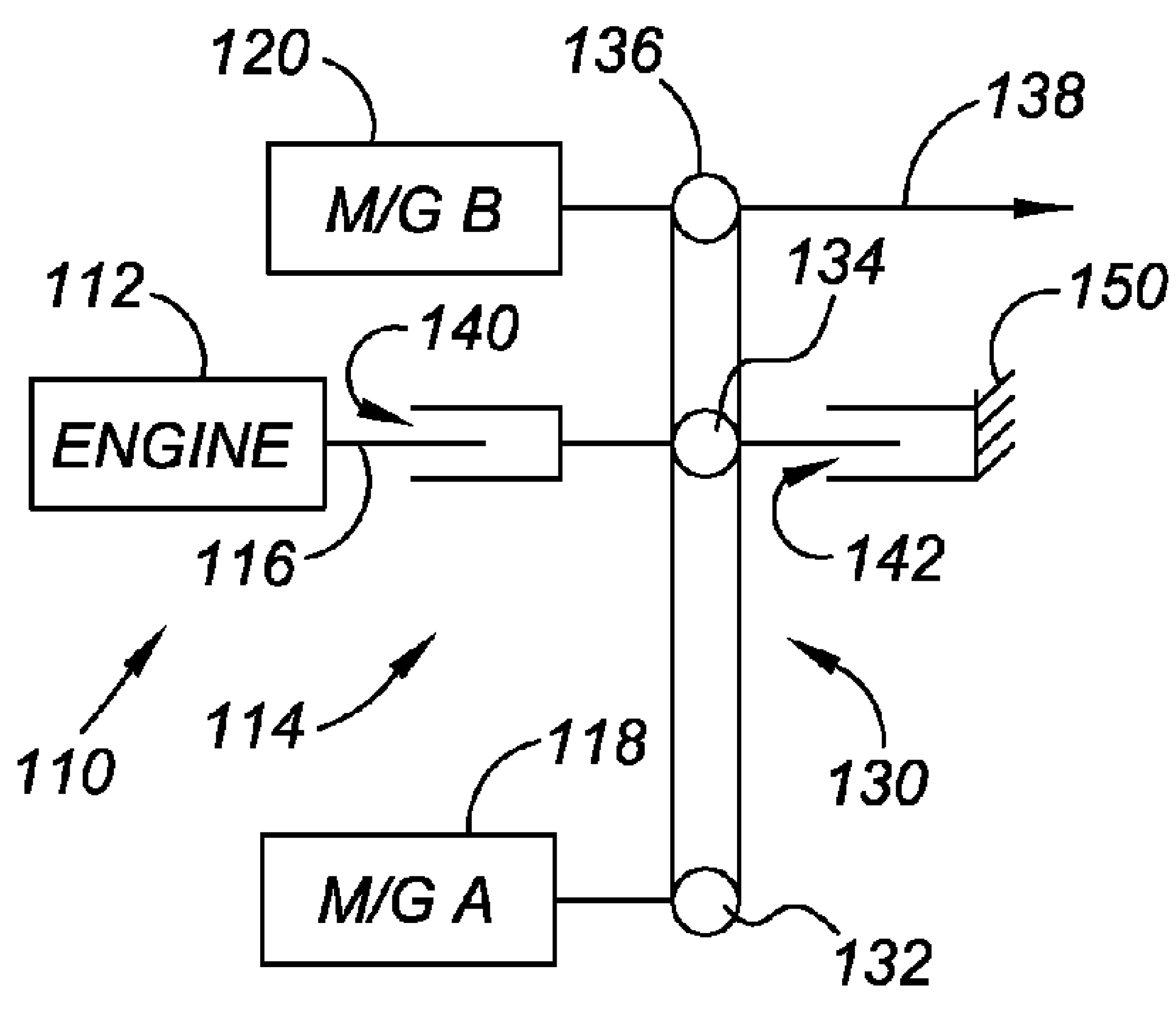


FIG. 2

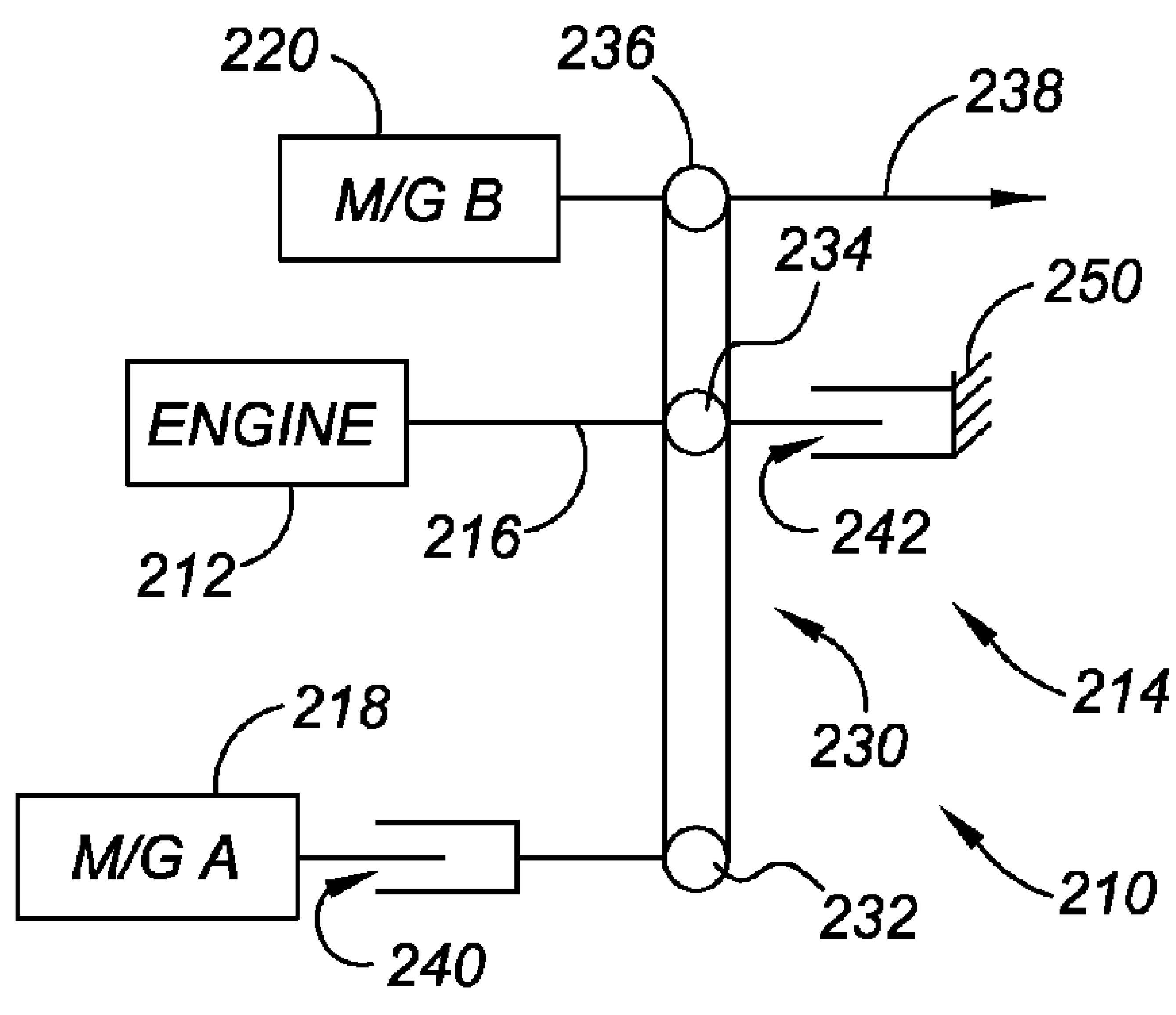
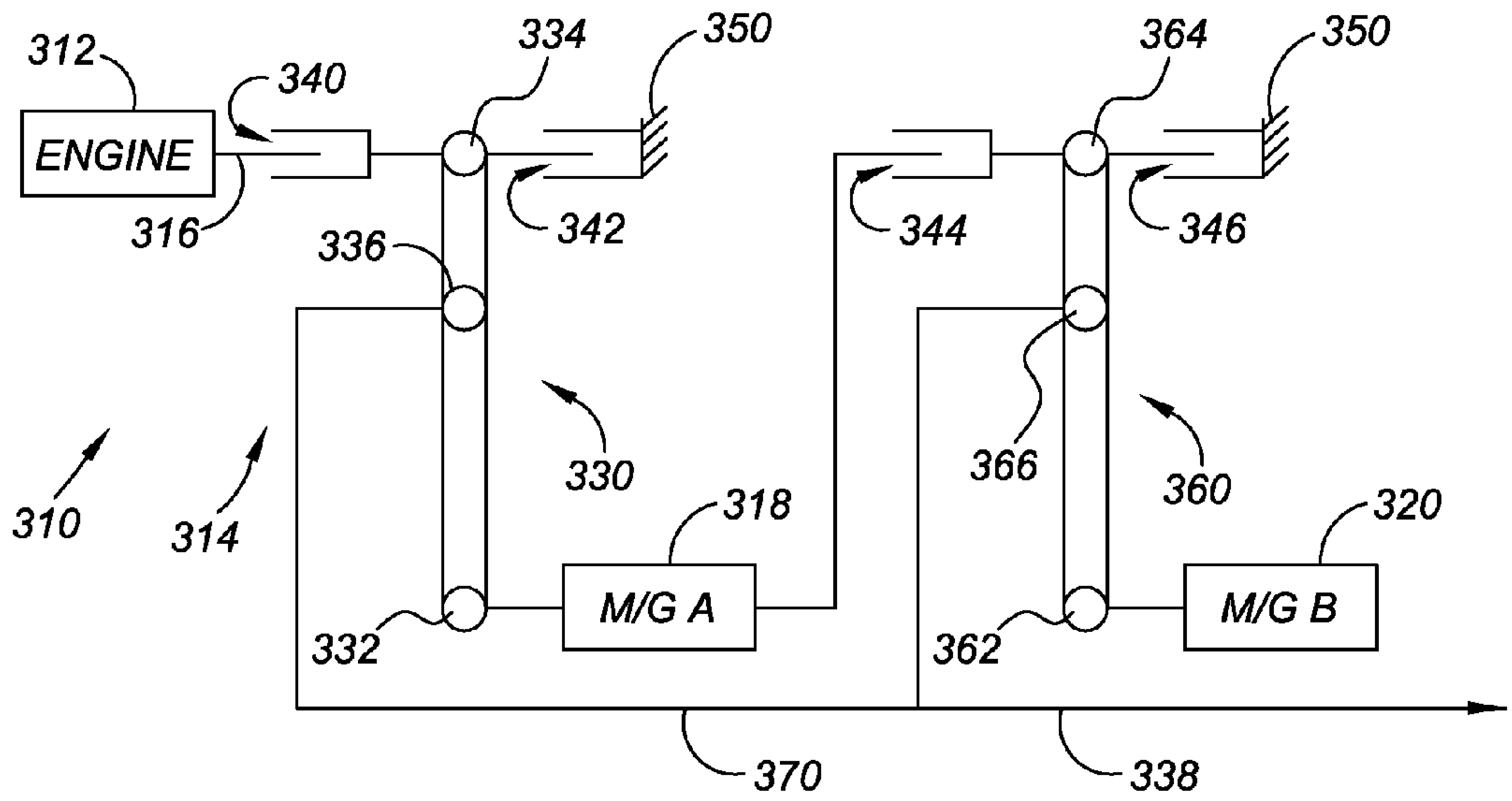


FIG. 3



ENGINE
M/G A
M/G B
312
340
334
350
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318
320
332
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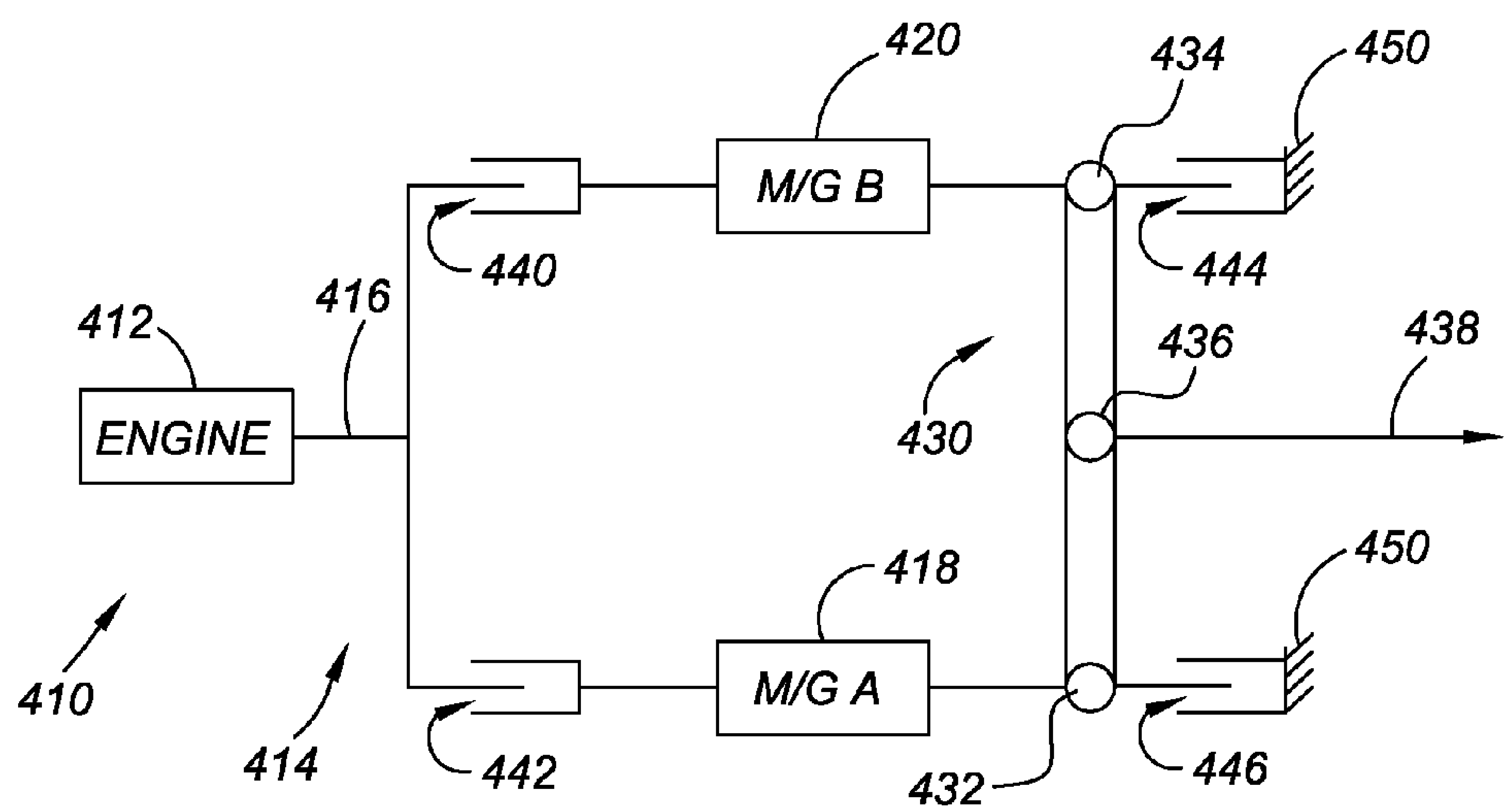
370
338

FIG. 4



ENGINE
M/G B
M/G A
420
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FIG. 5

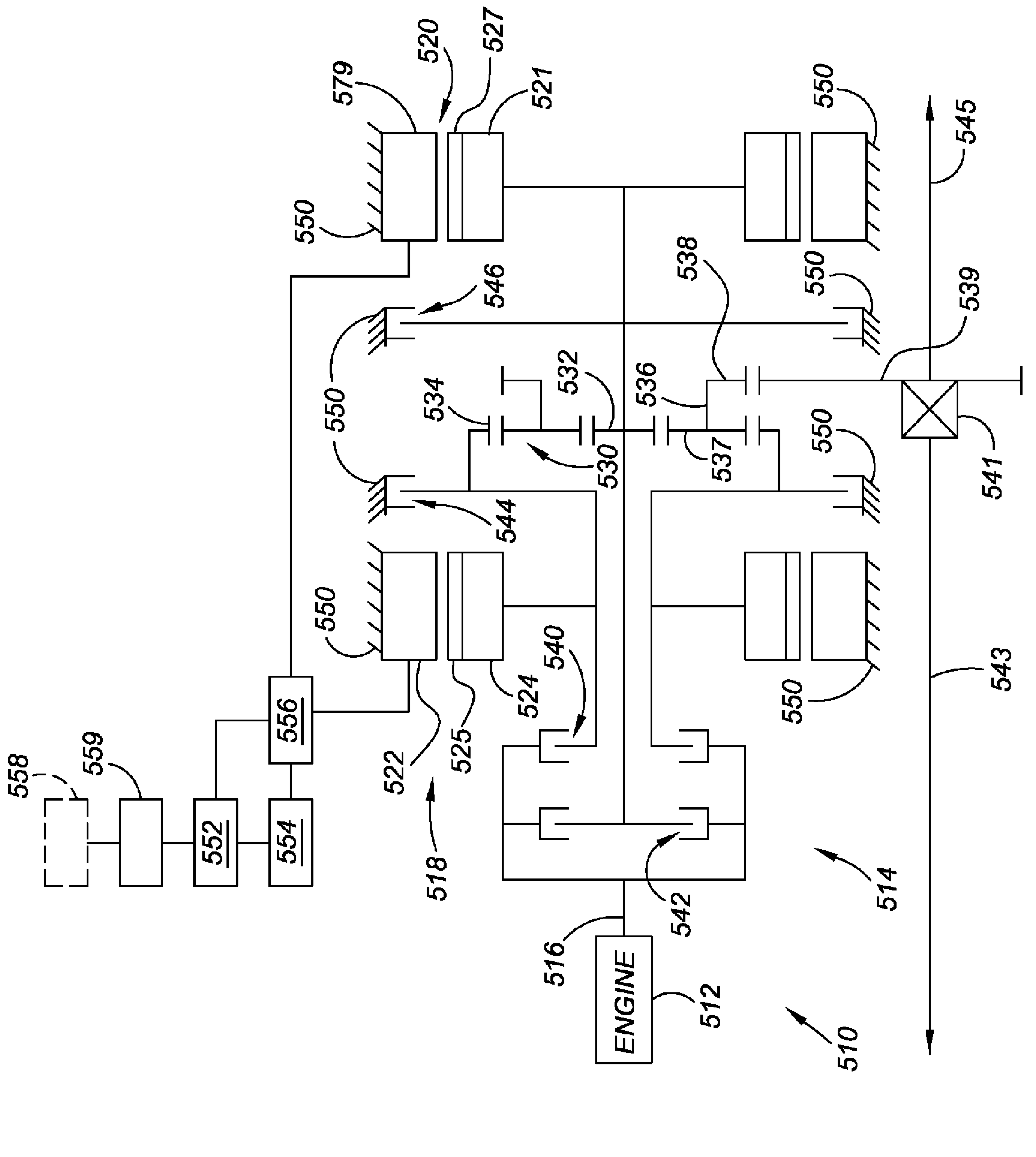
ENGINE
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FIG. 6

HYBRID POWERTRAIN

TECHNICAL FIELD

The invention relates to a hybrid powertrain with an electric-only operating mode in which multiple motor/generators act as motors to provide torque at an output member.

BACKGROUND OF THE INVENTION

Electrically-variable transmissions typically have an input member connected to an engine and one or two motor/generators connected to different members of planetary gear sets to allow one or more electrically-variable modes of operation, fixed speed ratio modes, and an electric-only (battery powered) mode, when connected with a battery. Electrically-variable transmissions may improve vehicle fuel economy in a variety of ways. For instance, the engine may be turned off at idle, during periods of deceleration and braking, and during periods of low speed or light load operation to eliminate efficiency losses due to engine drag. Captured braking energy (via regenerative braking) or energy stored by one of the motors acting as a generator during periods when the engine is operating is utilized during these engine off periods to keep the engine off longer, supplement engine torque or power and/or operate at a lower engine speed, or supplement accessory power supplies. Transient demand for engine torque or power is supplemented by the motor/generators during operation in engine-on, electrically-variable modes, allowing for downsizing the engine without reducing apparent vehicle performance. Additionally, the engine may be operated at or near the optimal efficiency point for a given power demand because the speed ratio between the engine and the output member of the transmission can be continuously variable by the action of a gear set and a motor/generator. Additionally, the motor/generators are very efficient in accessory power generation and electric power from the battery serves as an available torque reserve allowing operation at a relatively low transmission numerical speed ratio.

SUMMARY OF THE INVENTION

A hybrid powertrain of improved efficiency is provided that operates in an electric-only operating mode in which multiple motor/generators act as motors to provide torque at an output member. Each of the motor/generators may be separately controlled, which allows the powertrain to operate more efficiently than if only a single motor/generator acts as a motor in an electric-only operating mode. When a single motor/generator must power the vehicle in an electric-only operating mode, it must be designed to cover a large range of operating conditions, including conditions that require the ability to operate at a certain peak capability at which it is less efficient than under more typical operating conditions.

Specifically, a hybrid powertrain is provided that includes an engine operatively connected with an input member. The engine is not limited to a certain type of engine and could be an internal combustion engine, a diesel engine, a fuel cell, etc. The powertrain includes a transmission with a first and a second electric motor/generator, a differential gear set having multiple members, and selectively engagable torque-transmitting mechanisms. The input member, the output member, the engine and the motor/generators are selectively interconnected through the differential gear set by engagement of the torque-transmitting mechanisms in different combinations. An electronic controller operatively connected to the electric motor/generators and is configured to control the electric motor/generators, the engine and the torque-transmitting mechanisms to provide multiple operating modes between the input member and the output member, including an electric-only operating mode in which one of the first and second electric motor/generators acts as a motor to provide torque at the output member while the other of the first and second electric motor/generators is held to, or is controlled by the controller to, or is free to seek at equilibrium (i.e., because its speed not constrained by the differential gear set) a stationary or near stationary speed to minimize losses. Another electric-only operating mode is also available in which the engine is off and an electric-only operating mode in which the engine is off and both electric motor/generators act as motors to provide torque at the output member. Preferably, an engine-only operating mode is available, as well as at least one electrically-variable operating mode, which may be input-split, output-split, or compound-split, depending on the specific transmission arrangement.

The transmission may be a "plug-in" hybrid transmission in that an energy storage device connected to each of the motor/generators for providing power thereto or receiving power therefrom may be configured to be operatively connectable with an offboard power supply for recharging the energy storage device.

As used herein, a motor/generator "acts as a motor" when it receives stored energy from the energy storage device in order to provide mechanical power to the transmission. A motor/generator "acts as a generator" when it receives mechanical power from the transmission in order to provide energy to the energy storage device.

Within the scope of the invention, the motor/generators may have substantially identical maximum torque and power output, substantially identical input voltage and input current requirements, or may be different in these aspects. Thus, considerable flexibility in designing the engine to meet different desired operating capabilities and spatial packaging requirements is afforded.

The above features and advantages and other features and advantages of the present invention are readily apparent from the following detailed description of the best modes for carrying out the invention when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic illustration of a first embodiment of a hybrid powertrain having one differential gear set shown in lever diagram form;

FIG. **2** is a schematic illustration of a second embodiment of a hybrid powertrain having one differential gear set shown in lever diagram form;

FIG. **3** is a schematic illustration of a third embodiment of a hybrid powertrain having one differential gear set shown in lever diagram form;

FIG. **4** is a schematic illustration of a fourth embodiment of a hybrid powertrain having two differential gear sets shown in lever diagram form;

FIG. **5** is a schematic illustration of a fifth embodiment of a hybrid powertrain having one differential gear set shown in lever diagram form; and

FIG. **6** is a schematic illustration of the hybrid powertrain of FIG. **5** in stick diagram form.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings, wherein like reference numbers refer to like components, FIG. **1** shows a hybrid powertrain **10** that includes an engine **12** operatively connected with a hybrid transmission **14**. Within the scope of the invention, the engine **12** may be an internal combustion engine, a diesel engine, a fuel cell, or any other known power plant.

The hybrid transmission **14** includes an input member **16** operatively connected for rotation with an engine output member, such as through a dampening mechanism, as is known. The hybrid transmission **14** includes a first motor/generator **18**, labeled M/G A, and a second motor/generator **20**, labeled M/G B, both of which are operatively connectable to a differential gear set **30**. The motor/generators **18**, **20** each include a rotor portion and a stator portion, as is known. Connections of either of the motor/generators **18**, **20** to other components of the powertrain **10** such as to members of the differential gear set **30**, whether fixed connections or selective connections, are connections with the respective rotor portions of the motor/generators **18**, **20**.

The differential gear set **30** has a first member **32** that is continuously connected for common rotation with motor/generator **18**, a second member **34**, and a third member **36** that is continuously connected for common rotation with an output member **38**. The differential gear set **30** is shown in lever diagram form, with the members represented as nodes on a lever, as is understood by those skilled in the art. The differential gear set is preferably a planetary gear set having a sun gear member, a ring gear member, and a carrier member that rotatably supports a plurality of pinion gears that mesh with the sun gear member and the ring gear member. For example, the first member **32** may be a sun gear member, the second member **34** may be a ring gear member, and the third member **36** may be a carrier member. Many alternate embodiments of differential gear sets, well known to those skilled in the art, may be utilized in the invention. For example, the first member **32** may be a sun gear member, the second member **34** may be a carrier member supporting pairs of intermeshing pinion gears, and the third member **36** may be a ring gear member.

The hybrid transmission **14** includes a plurality of torque-transmitting mechanisms including a first torque-transmitting mechanism **40** that is selectively engagable to connect the input member **16** with the motor/generator **20**, a second torque-transmitting mechanism **42** that is selectively engagable to connect the motor/generator **20** with the second member **34**, and a third torque-transmitting mechanism **44** that is selectively engagable to ground the second member **34** to a stationary housing **50**, such as a casing for the transmission **14**. The torque-transmitting mechanisms **40** and **42** may be rotating friction clutches, dog clutches or any other suitable type of torque-transmitting mechanism. The torque-transmitting mechanism **44** may be a friction clutch with a stationary component, and may be referred to as a brake.

The powertrain **10** has an onboard energy storage device **52** that is operatively connected to the motor/generators **18**, **20** such that the motor/generators **18**, **20** may transfer power to or receive power from the energy storage device **52**. An electronic controller **54** is operatively connected to the energy storage device **52** to control the distribution of power from or to the energy storage device to the motor/generators **18**, **20** through a power inverter **56**. The controller **54** (or one or more separate controllers) is also operatively connected to the engine **12** and the torque-transmitting mechanisms **40**, **42**, **44**, and controls engagement and disengagement thereof based on vehicle operating conditions. As used herein, an "onboard" energy storage device is an energy storage device that is designed for mounting on a vehicle to which the associated powertrain with the motor/generators is also mounted. An onboard energy storage device may be one or more batteries. Other onboard energy storage devices, such as fuel cells or capacitors, have the ability to provide, or store and dispense, electric power and may be used in combination with or in place of batteries. Operating data gathered by sensors, such as the speed of the input member **16** and of the output member **38**, may be provided to the controller as well, for various uses, such as when operating in a regenerative braking mode.

The transmission **14** is configured so that an offboard power supply system **58** may be connected with the energy storage device **52** for recharging of the energy storage device **52**. The offboard power supply system **58** connects with the energy storage device **52** via an interface **59**. The interface **59** may be a plug, in which case an onboard charger (not shown) would be electrically connected between the plug and the energy storage device **52**. Such a transmission is referred to as a plug-in hybrid. Alternatively, the interface **59** may be conductive, in which case an offboard charger may be connected between the offboard power supply system **58** and the interface **59**, or inductive, in which case an offboard inductive charger would be connected between the offboard power supply **58** and the interface **59**. When the energy storage device **52** is sufficiently recharged, the connection through interface **59** is terminated, and the recharged energy storage device **52** is then used under the control of controller **54** to power the motor/generators **18**, **20**, such as in an electric-only mode (i.e., an operating mode in which only the motor/generators and not the engine, power the vehicle).

It should be appreciated that each of the powertrain embodiments of FIGS. **2**-**7** also include a similar energy storage device **52**, controller **54**, and inverter **56** for connection to the engine, motor/generators and torque-transmitting mechanisms described therein, although these are not shown in FIGS. **2**-**5** for purposes of clarity in the drawings, but will be readily understood by those skilled in the art of transmission design. The energy storage device of each of the powertrains of FIGS. **2**-**7** may also be configured for connection to an offboard power supply and include an interface, as does powertrain **10**.

The engine **12** and motor/generators **18** and **20** are selectively interconnected through the differential gear set **30** by engagement of the torque-transmitting mechanisms **40**, **42**, **44** in different combinations, to establish different operating modes for the hybrid powertrain **10**. For example, the powertrain **10** may be used to launch a vehicle either with the engine off or running. If the engine is off, torque-transmitting mechanism **44** is engaged to ground member **34** and motor/generator **18** is operated as a motor to provide torque in a forward direction at the output member **38**. An electrically-variable series hybrid operating mode is provided when engine **12** is on, torque-transmitting mechanism **40** is engaged so that the engine **12** provides power to motor/generator **20**, which acts as a generator, providing power to the energy storage device **52** through the inverter **56**, and motor/generator **18** acts as a motor with torque-transmitting mechanism **44** engaged. Alternatively, an engine-only operating mode is established by the engaging torque-transmitting mechanisms **40** and **42** and turning off both motor/generators **18**, **20**.

The powertrain **10** is operable in an electric-only operating mode in which only motor/generator **18** acts as a motor, and torque-transmitting mechanism **44** is engaged. Motor/generator **20** can remain stationary as torque-transmitting mechanism **42** is not engaged. Alternatively, torque-transmitting mechanism **42** may be engaged and both motor/generators **18** and **20** may be controlled to act as motors in a second, load-sharing electric-only mode, to provide power through the differential gear set **30** to the output member **38**. This allows a large amount of power to be provided during the electric-only operating mode, while using two motor/generators of a smaller size than the size of a single motor/generator that could provide the same amount of power. In the first of the electric-only operating modes, the torque from motor/generator **18** is added by the differential gear set **30** to reaction torque from the stationary housing **50**, but the stationary housing **50** can only contribute torque, and not power. In the second electric-only operating mode, the load-sharing electric-only mode, the motor/generator **20** must supply torque instead of the stationary housing **50**. This requires additional electrical input from the inverter **56**, but the motor/generator **20** can also supply speed and therefore power to be added to that from motor/generator **18**. Because a single motor need not cover the wide range of possible operating conditions, each motor/generator **18**, **20** can be designed with a lesser peak capability than a powertrain **10** that relies on tractive power from only one electric motor/generator.

Typically, the torque curve of an electric motor/generator has a speed range of substantially constant torque, followed by a speed range of decreasing power, up to the mechanical speed limit of the motor. Typically, an electric motor/generator has its best efficiency at the center of this operating range. Load-sharing between electric motor/generators **18** and **20** using the speed-adding action of the differential gear set **30** is a selectable option for operation, so that the motor/generators can thus be designed to operate within a more efficient operating range which is suitable for most typical vehicle operating conditions. In another, electrically-variable operating mode, torque-transmitting mechanisms **40** and **42** are engaged and motor/generators **18** and **20** act as either a motor or a generator, depending on operating conditions, with power split through the differential gear set **30**. This may be referred to as an electrically-variable, output-split operating mode.

Because the motor/generators **18**, **20** are both controllable to act as motors in one of the electric-only operating modes, neither need be designed to provide as large a power output as would be required if only one of the motor/generators could act as a motor in an electric-only operating mode. The motor/generators **18**, **20** may be designed with the same or different maximum torque and/or power outputs, torque and/or power outputs for best motor efficiency, input voltage requirement, and/or input current requirements. One advantage of the motor/generators **18**, **20** having substantially identical torque, power and current characteristics is the economies of scale when purchasing or constructing and storing the motor/generators, and when assembling the powertrain **10** with identical motor/generators. The motor/generators described below with respect to each of the powertrains of FIGS. **2-7** may also be designed with the same or different maximum torque and/or power outputs, input voltage requirement, and/or input current requirements as well.

FIG. **2** shows a hybrid powertrain **110** that includes an engine **112** operatively connected with a hybrid transmission **114**. Within the scope of the invention, the engine **112** may be an internal combustion engine, a diesel engine, a fuel cell, or any other known power plant.

The hybrid transmission **114** includes an input member **116** operatively connected for rotation with an engine output member, such as through a dampening mechanism, as is known. The hybrid transmission **114** includes a first motor/generator **118**, labeled M/G A, and a second motor/generator **120**, labeled M/G B, both of which are operatively connectable to a differential gear set **130**. The motor/generators **118**, **120** each include a rotor portion and a stator portion, as is known. Connections of either of the motor/generators **118**, **120** to other components of the powertrain **110** such as to members of the differential gear set **130**, whether fixed connections or selective connections, are connections with the respective rotor portions of the motor/generators **118**, **120**.

The differential gear set **130** has a first member **132** that is continuously connected for common rotation with motor/generator **118**, a second member **134**, and a third member **136** that is continuously connected for common rotation with an output member **138** and with the second motor/generator **120**. The differential gear set **130** is shown in lever diagram form, with the members represented as nodes on a lever, as is understood by those skilled in the art. The differential gear set **130** is preferably a planetary gear set having a sun gear member, a ring gear member, and a carrier member that rotatably supports a plurality of pinion gears that mesh with the sun gear member and the ring gear member. For example, the first member **132** may be a sun gear member, the second member **134** may be a carrier member, and the third member **136** may be a ring gear member.

The hybrid transmission **114** includes a plurality of torque-transmitting mechanisms including a first torque-transmitting mechanism **140** that is selectively engagable to connect the input member **116** with the second member **134**, and a second torque-transmitting mechanism **142** that is selectively engagable to ground the second member **134** to a stationary housing **150**, such as a casing for the transmission **114**. The torque-transmitting mechanism **140** may be a rotating friction clutch, dog clutch or any other suitable type of torque-transmitting mechanism. The torque-transmitting mechanism **142** may be a friction clutch with a stationary component, and may be referred to as a brake.

The engine **112** and motor/generators **118** and **120** are selectively interconnected through the differential gear set **130** by engagement of the torque-transmitting mechanisms **140**, **142** in different combinations, to establish different operating modes for the hybrid powertrain **110**. For example, the powertrain **110** may be used to launch a vehicle either with the engine off or running. If the engine is off, torque-transmitting mechanism **142** is engaged to ground the second member **134** and either or both motor/generators **118** and **120** are operated as motors to provide torque in a forward direction at the output member **138**. If the engine **112** is on, torque-transmitting mechanism **140** is engaged so that the engine **112** provides power to the second member **134** and motor/generators **118** and **120** are controlled independently to act as motors or generators depending on vehicle operating conditions, to establish an input-split electrically-variable hybrid operating mode. Alternatively, an engine-only operating mode is available if torque-transmitting mechanism **140** is engaged, the engine **112** is on, and the motor/generators **118**, **120** are turned off.

The powertrain **110** is operable in an electric-only operating mode in which only motor/generator **120** acts as a motor. Neither of the torque-transmitting mechanisms **140**, **142** are engaged, so the second member **134** can rotate at any speed. Thus, the speed of motor/generator **118** is not determined by the gear set **130**, and motor/generator **118** can be controlled to be substantially stationary, or will free-wheel to an equilibrium speed substantially near zero that minimizes losses. Alternatively, in another electric-only operating mode, torque-transmitting mechanism **142** may be engaged and both motor/generators **118** and **120** may be controlled to act as motors to provide power through the differential gear set **130** to the output member **138**.

FIG. **3** shows a hybrid powertrain **210** that includes an engine **212** operatively connected with a hybrid transmission

214. Within the scope of the invention, the engine **212** may be an internal combustion engine, a diesel engine, a fuel cell, or any other known power plant.

The hybrid transmission **214** includes an input member **216** operatively connected for rotation with an engine output member, such as through a dampening mechanism, as is known. The hybrid transmission **214** includes a first motor/generator **218**, labeled M/G A, and a second motor/generator **220**, labeled M/G B, both of which are operatively connectable to a differential gear set **230**. The motor/generators **218**, **220** each include a rotor portion and a stator portion, as is known. Connections of either of the motor/generators **218**, **220** to other components of the powertrain **210** such as to members of the differential gear set **230**, whether fixed connections or selective connections, are connections with the respective rotor portions of the motor/generators **218**, **220**.

The differential gear set **230** has a first member **232**, a second member **234** continuously connected for common rotation with the input member **216**, and a third member **236** that is continuously connected for common rotation with an output member **238** and with the second motor/generator **220**. The differential gear set **230** is shown in lever diagram form, with the members represented as nodes on a lever, as is understood by those skilled in the art. The differential gear set **230** is preferably a planetary gear set having a sun gear member, a ring gear member, and a carrier member that rotatably supports a plurality of pinion gears that mesh with the sun gear member and the ring gear member. For example, the first member **232** may be a sun gear member, the second member **234** may be a ring gear member, and the third member **236** may be a carrier member.

The hybrid transmission **214** includes a plurality of torque-transmitting mechanisms including a first torque-transmitting mechanism **240** that is selectively engagable to connect the first motor/generator **218** with the first member **232**, and a second torque-transmitting mechanism **242** that is selectively engagable to ground the second member **234** to a stationary housing **250**, such as a casing for the transmission **214**. The torque-transmitting mechanism **240** may be a rotating friction clutch, dog clutch or any other suitable type of torque-transmitting mechanism. The torque-transmitting mechanism **242** may be a friction clutch with a stationary component, and may be referred to as a brake.

The engine **212** and motor/generators **218** and **220** are selectively interconnected through the differential gear set **230** by engagement of the torque-transmitting mechanisms **240**, **242** in different combinations, to establish different operating modes for the hybrid powertrain **210**. For example, the powertrain **210** may be used to launch a vehicle either with the engine off or running. If the engine **212** is off, torque-transmitting mechanism **242** is engaged to ground the second member **234** and motor/generator **220** is operated as a motor to provide torque in a forward direction at the output member **238**. If torque-transmitting mechanisms **240** and **242** are both engaged, both motor/generators **218**, **220** can be operated as motors to provide torque in a forward direction at the output member **238**. If the engine **212** is on, torque-transmitting mechanism **240** can be engaged and motor/generators **218** and **220** controlled independently to act as motors or generators depending on vehicle operating conditions, to establish an input-split electrically-variable hybrid operating mode.

The powertrain **210** is operable in an electric-only operating mode in which only motor/generator **220** acts as a motor. Because torque-transmitting mechanism **240** is disengaged, motor/generator **218** remains substantially stationary regardless of the speed of the member **232**. Alternatively, in another electric-only operating mode, torque-transmitting mechanisms **240** and **242** are engaged and both motor/generators **218** and **220** may be controlled to act as motors to provide power through the differential gear set **230** to the output member **238**. The powertrain **210** is also operable in an engine-only operating mode in which neither torque-transmitting mechanisms **240** or **242** is engaged, the motor/generators **218** and **220** are turned off, and the engine **212** provides power to the output member **238**, with the differential gear set **230** being inactive.

FIG. **4** shows a hybrid powertrain **310** that includes an engine **312** operatively connected with a hybrid transmission **314**. Within the scope of the invention, the engine **312** may be an internal combustion engine, a diesel engine, a fuel cell, or any other known power plant.

The hybrid transmission **314** includes an input member **316** operatively connected for rotation with an engine output member, such as through a dampening mechanism, as is known. The hybrid transmission **314** includes a first motor/generator **318**, labeled M/G A, and a second motor/generator **320**, labeled M/G B. Motor/generator **318** is continuously operatively connected with a first differential gear set **330**, as described below, and motor/generator **320** is continuously connected with a second differential gear set **360**. The motor/generators **318**, **320** each include a rotor portion and a stator portion, as is known. Connections of either of the motor/generators **318**, **320** to other components of the powertrain **310** such as to members of the differential gear set **330**, whether fixed connections or selective connections, are connections with the respective rotor portions of the motor/generators **318**, **320**.

The differential gear set **330** has a first member **332** continuously connected for common rotation with the first motor/generator **318**, a second member **334**, and a third member **336**. The differential gear set **330** is shown in lever diagram form, with the members represented as nodes on a lever, as is understood by those skilled in the art. The differential gear set **330** is preferably a planetary gear set having a sun gear member, a ring gear member, and a carrier member that rotatably supports a plurality of pinion gears that mesh with the sun gear member and the ring gear member. For example, the first member **332** may be a sun gear member, the second member **334** may be a ring gear member, and the third member **336** may be a carrier member.

The differential gear set **360** has three members, referred to herein as a fourth member **362**, a fifth member **366**, and a sixth member **364**. The fourth member **362** is continuously connected for common rotation with the second motor/generator **320**. The transmission **314** includes an interconnecting member **370** that continuously connects the third member **336** and the fifth member **366** for common rotation with an output member **338**. The differential gear set **360** is shown in lever diagram form, with the members represented as nodes on a lever, as is understood by those skilled in the art. The differential gear set **360** is preferably a planetary gear set having a sun gear member, a ring gear member, and a carrier member that rotatably supports a plurality of pinion gears that mesh with the sun gear member and the ring gear member. For example, the fourth member **362** may be a sun gear member, the fifth member **366** may be a carrier member, and the sixth member **364** may be a ring gear member.

The hybrid transmission **314** includes a plurality of torque-transmitting mechanisms including a first torque-transmitting mechanism **340** that is selectively engagable to connect the input member **316** with the second member **334**. A second torque-transmitting mechanism **342** is selectively engagable to ground the second member **334** with a stationary member **350**, such as a casing for the transmission **314**. A third torque-transmitting mechanism **344** is selectively engagable to connect the first motor/generator **318** and the first member **332** for common rotation with the sixth member **364**. A fourth torque-transmitting mechanism **346** is selectively engagable to ground the sixth member **364** to the stationary member **350**. The torque-transmitting mechanisms **340** and **344** may be rotating friction clutches, dog clutches or any other suitable type of torque-transmitting mechanisms. The torque-transmitting mechanisms **342** and **346** may be friction clutches with a stationary component, and may be referred to as brakes.

The engine **312** and motor/generators **318** and **320** are selectively interconnected through the differential gear sets **330** and **360** by engagement of the torque-transmitting mechanisms **340**, **342**, **344**, and **346** in different combinations, to establish different operating modes for the hybrid powertrain **310**. For example, the powertrain **310** may be used to launch a vehicle either with the engine off or running. If the engine **312** is off, any one of four operating modes can be used. In the first of these electric-only operating modes, torque-transmitting mechanism **342** alone is engaged, to ground member **334**, and motor/generator **318** alone is operated as a motor to provide torque through gear set **330** to the output member **338**. Because the torque-transmitting mechanisms **344** and **346** are not engaged, the speeds of the sixth member **364** and the fourth member **362** are not determined by the gear set **360**. The motor/generator **320** can be controlled to zero speed (stationary) or will assume an equilibrium speed that minimizes losses and is substantially zero. In the second electric-only mode, torque-transmitting mechanism **346** alone is engaged to ground member **364**, and motor/generator **320** alone is operated as a motor to provide torque through gear set **360** to the output member **338**. Because the torque-transmitting mechanisms **340**, **342** and **344** are not engaged, the first and second members **332** and **334** will seek an equilibrium speed that minimizes losses in which the speed of the motor/generator **318** is zero or substantially zero, or the motor/generator **318** may be controlled to be stationary. In the third electric-only mode, both torque-transmitting mechanisms **342** and **346** are engaged and both motor/generators **318** and **320** are operated as motors to provide torque in a forward direction at the output member **338**. In the fourth electric-only mode, only torque-transmitting mechanism **344** is engaged, to connect motor/generator **318** to member **364**, and both motor/generators **318** and **320** are used to provide forward torque through gear set **360** to the output member **338**.

If the engine **312** is on, torque-transmitting mechanism **340** can be engaged and torque-transmitting mechanism **342** disengaged, and motor/generator **318** can be controlled to act as either a motor or a generator, depending on vehicle operating conditions, to establish an input-split electrically-variable hybrid operating mode. A second electrically-variable mode can be established by then engaging torque-transmitting mechanism **344** in addition to torque-transmitting mechanism **340**, and controlling motor/generator **320** to act as either a motor or a generator as well, establishing a compound-split electrically-variable hybrid operating mode, providing power at the output member **338** through the differential gear sets **330**, **360**.

FIG. **5** shows a hybrid powertrain **410** that includes an engine **412** operatively connected with a hybrid transmission **414**. Within the scope of the invention, the engine **412** may be an internal combustion engine, a diesel engine, a fuel cell, or any other known power plant.

The hybrid transmission **414** includes an input member **416** operatively connected for rotation with an engine output member, such as through a dampening mechanism, as is known. The hybrid transmission **414** includes a first motor/generator **418**, labeled M/G A, and a second motor/generator **420**, labeled M/G B. Motor/generator **418** and **420** are both continuously operatively connected with a differential gear set **430**, as described below. The motor/generators **418**, **420** each include a rotor portion and a stator portion, as is known. Connections of either of the motor/generators **418**, **420** to other components of the powertrain **410** such as to members of the differential gear set **430**, whether fixed connections or selective connections, are connections with the respective rotor portions of the motor/generators **418**, **420**.

The differential gear set **430** has a first member **432** continuously connected for common rotation with the first motor/generator **418**, a second member **434** continuously connected for common rotation with the second motor/generator **420**, and a third member **436** continuously connected for common rotation with output member **438**. The differential gear set **430** is shown in lever diagram form, with the members represented as nodes on a lever, as is understood by those skilled in the art. The differential gear set **430** is preferably a planetary gear set having a sun gear member, a ring gear member, and a carrier member that rotatably supports a plurality of pinion gears that mesh with the sun gear member and the ring gear member. For example, the first member **432** may be a sun gear member, the second member **434** may be a ring gear member, and the third member **436** may be a carrier member.

The hybrid transmission **414** includes a plurality of torque-transmitting mechanisms including a first torque-transmitting mechanism **440** that is selectively engagable to connect the input member **416** with the second member **434**. A second torque-transmitting mechanism **442** is selectively engagable to connect the input member **416** with the first member **432**. A third torque-transmitting mechanism **444** is selectively engagable to ground the second member **434** and the motor/generator **420** to the stationary member **450**. A fourth torque-transmitting mechanism **446** is selectively engagable to ground the first member **432** and the motor/generator **418** to the stationary member **450**. The torque-transmitting mechanisms **440** and **442** may be rotating friction clutches, dog clutches or any other suitable type of torque-transmitting mechanisms. The torque-transmitting mechanisms **444** and **446** may be friction clutches with a stationary component, and may be referred to as brakes.

The engine **412** and motor/generators **418** and **420** are selectively interconnected through the differential gear set **430** by engagement of the torque-transmitting mechanisms **440**, **442**, **444**, and **446** in different combinations, to establish different operating modes for the hybrid powertrain **410**. For example, in one electric-only operating mode, if the engine **412** is off, the motor/generator **418** may be used alone as a motor to provide power at the output member **438** if torque-transmitting mechanism **444** is engaged. Motor/generator **420** will be stationary. Alternatively, in another electric-only operating mode, motor/generator **420** may be used alone as a motor to provide power at the output member **438** if torque-transmitting mechanism **446** is engaged. Motor/generator **418** will be stationary. In yet another electric-only operating mode, if none of the torque-transmitting mechanisms are engaged, both motor/generators **418** and **420** may be operated as motors to provide torque in a forward direction at the output member **438**. The motor/generators **418** and **420** may be substantially identical and connected to members **432** and **434** of the differential gear set **430**, wherein the members **432** and **434** have substantially different numbers of teeth and therefore a substantially different torque ratio and speed ratio between each of the motors **418** and **420** is established with the output **438**, so that the controller (not shown) has two different choices for operation with one motor alone. Alternately, the motor/generators **418** and **420** may be substantially different in torque and power capacity and in torque and power output for best efficiency, so that the controller (not shown) has two different choices for operation with one motor alone, each of which may be most efficient in some of the various powertrain operating conditions. Furthermore, the motor/generators **418** and **420** may be different in general type, e.g. one induction motor/generator and one permanent-magnet magnet motor/generator, or in specific type of permanent magnet motor/generator, e.g. one relying almost exclusively on torque produced by permanent magnets (such as a flat-magnet or surface-magnet type) and one relying on comparable amounts of torque produced by permanent magnets and by iron in the rotor (such as a V-magnet type) with substantially different characteristics, each appropriate for different powertrain operating conditions. Such similarities or differences in motor/generators may also be utilized in each of the other embodiments described herein.

If the engine **412** is on, torque-transmitting mechanism **440** can be engaged, while motor/generator **418** is controlled to act as either a motor or a generator, depending on vehicle operating conditions, to establish an input-split electrically-variable hybrid operating mode. A second input-split electrically-variable mode can be established by instead engaging torque-transmitting mechanisms **442**, and controlling motor/generator **420** to act as either a motor or a generator to providing power at the output member **438** through the differential gear set **430**. A fixed speed ratio may be established between the input member **416** and the output member **438** by engaging both torque-transmitting mechanisms **440** and **446**. A fixed speed ratio is also selectable by engaging both torque transmitting mechanisms **442** and **444**. Another fixed speed ratio, direct drive, is selectable by engaging both torque transmitting mechanisms **440** and **442**.

FIG. **6** is a powertrain **510** in stick diagram form that represents one embodiment of the powertrain **410** of FIG. **5** in lever diagram form. The powertrain **510** includes an engine **512** operatively connected with a hybrid transmission **514**. Within the scope of the invention, the engine **512** may be an internal combustion engine, a diesel engine, a fuel cell, or any other known power plant.

The hybrid transmission **514** includes an input member **516** operatively connected for rotation with an engine output member, such as through a dampening mechanism, as is known. The hybrid transmission **514** includes a first motor/generator **518** that includes a stator portion **522** grounded to a stationary member **550**, such as a transmission casing. The motor/generator **518** also includes a rotor portion **524**. The rotor portion **524** has permanent magnets **525** circumferentially spaced therearound such that the electric motor/generator **518** is a permanent-magnet motor/generator. A second motor/generator **520** includes a stator portion **579** grounded to the stationary member **550** and a rotor portion **521**. The rotor portion **521** has slots **527** circumferentially spaced therearound such that the electric motor/generator **520** is a reluctance motor/generator.

The powertrain **510** includes a differential gear set **530** that is a planetary gear set and may be referred to as planetary gear set **530**. The planetary gear set **530** includes a sun gear member **532**, a ring gear member **534** and a carrier member **536** that rotatably supports a set of pinion gears **537** that mesh with both the ring gear member **534** and the sun gear member **532**. A gear **538**, also referred to herein as the output member, rotates commonly with the carrier member **536** and meshes with a gear **539**. Gear **539** transfers torque to driveshafts **543**, **545** through a differential **541**.

The ring gear member **534** is connected for common rotation with the rotor portion **524** of the motor/generator **518**. The sun gear member **532** is connected for common rotation with the rotor portion **521** of the motor/generator **520**.

The hybrid transmission **514** includes a plurality of torque-transmitting mechanisms including a first torque-transmitting mechanism **540** that is selectively engagable to connect the input member **516** with the ring gear member **534**. A second torque-transmitting mechanism **542** is selectively engagable to connect the input member **516** with the sun gear member **532**. A third torque-transmitting mechanism **544** is selectively engagable to ground the ring gear member **534** and rotor portion **524** to the stationary member **550**. A fourth torque-transmitting mechanism **546** is selectively engagable to ground the sun gear member **532** and rotor portion **521** to the stationary member **550**. The torque-transmitting mechanisms **540** and **542** may be rotating friction clutches, dog clutches or any other suitable type of torque-transmitting mechanisms. The torque-transmitting mechanisms **544** and **546** may be friction clutches with a stationary component, and may be referred to as brakes.

The powertrain **510** has an onboard energy storage device **552** that is operatively connected to the motor/generators **518**, **520** such that the motor/generators **518**, **520** may transfer power to or receive power from the energy storage device **552**. An electronic controller **554** is operatively connected to the energy storage device **552** to control the distribution of power from or to the energy storage device to the motor/generators **518**, **520** through a power inverter **556**. The controller **554** (or one or more separate controllers) is also operatively connected to the engine **512** and the torque-transmitting mechanisms **540**, **542**, **544**, and **546**, and controls engagement and disengagement thereof based on vehicle operating conditions. Operating data gathered by sensors, such as the speed of the input member **516** and of the output member **538**, may be provided to the controller **554** as well, for various uses, such as when operating in a regenerative braking mode. The transmission **514** is configured so that an offboard power supply system **558** may be connected with the energy storage device **552** for recharging of the energy storage device **552**. The offboard power supply system **558** connects with the energy storage device **552** via an interface **559**, and may be configured as described with respect to the offboard power supply system **58** and interface **59** of FIG. **1**.

Because powertrain **510** is one embodiment of the powertrain **410**, each component of the powertrain **410** has a corresponding component on powertrain **510**. For example, the planetary gear set **530** corresponds with differential gear set **430**. Sun gear member **532** corresponds with first member **432**, ring gear member **534** corresponds with second member **434**, and carrier member **536** corresponds with the third member **436**. Motor/generators **518** and **520** correspond with motor/generators **418** and **420**, respectively. Torque-transmitting mechanisms **540**, **542**, **544**, and **546** correspond with torque-transmitting mechanisms **440**, **442**, **444**, and **446**, respectively. Input member **516** and output member **538** correspond with input member **416** and output member **438**, respectively.

The engine **512** and motor/generators **518** and **520** are selectively interconnected through the differential gear set **530** by engagement of the torque-transmitting mechanisms **540**, **542**, **544**, and **546** in different combinations, to establish different operating modes for the hybrid powertrain **510**. For example, if the engine **512** is off, in one electric-only operating mode, the motor/generator **520** may be used alone as a motor to provide power at the output member **538** if torque-transmitting mechanism **544** is engaged, with motor/generator **518** thereby being stationary. Alternatively, in another electric-only operating mode, motor/generator **518** may be used alone as a motor to provide power at the output member **538** if torque-transmitting mechanism **546** is engaged, with motor/generator **520** thereby being stationary. If none of the torque-transmitting mechanisms are engaged, both motor/generators **518** and **520** may be operated as motors to provide torque in a forward direction at the output member **538**. If the engine **512** is on, torque-transmitting mechanism **540** can be engaged, while motor/generator **520** is controlled to act as either a motor or a generator, depending on vehicle operating conditions, to establish an input-split electrically-variable hybrid operating mode. A second input-split electrically-variable mode can be established by instead engaging torque-transmitting mechanism **542** and controlling motor/generator **518** to act as either a motor or a generator to providing power at the output member **538** through the differential gear set **530**. Two engine-only operating modes are available when the engine **512** is on and both motor/generators **518**, **520** are turned off: a first engine-only operating mode is by engaging torque-transmitting mechanism **540** and a second is by engaging torque-transmitting mechanism **542**.

While the best modes for carrying out the invention have been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention within the scope of the appended claims.

The invention claimed is:

1. A hybrid powertrain comprising:

an input member;

an output member;

an engine operatively connected with the input member;

first and second electric motor/generators;

a differential gear set having multiple members;

selectively engageable torque-transmitting mechanisms; wherein at least some of the input member, the output member, the engine and the motor/generators are selectively interconnected through the differential gear set by engagement of different combinations of the torque-transmitting mechanisms;

an electronic controller operatively connected to the electric motor/generators and configured to control the electric motor/generators to provide multiple operating modes between the input member and the output member, including:

a first electric-only operating mode in which the engine is off, one of the first and second electric motor/generators acts as a motor to provide torque at the output member while the other of the first and second electric motor/generators is not connected to any of the members of the differential gear set and is able to remain substantially stationary; and

a second electric-only operating mode in which the engine is off and both first and second electric motor/generators act as motors to provide torque at the output member; and

wherein the engine is not continuously connected to any of the members of the differential gear set and is selectively connectable for common rotation with the second motor/generator by engagement of one of the torque-transmitting mechanisms.

2. The hybrid powertrain of claim **1**, wherein the first and second electric motor/generators are characterized by substantially identical maximum torque and power output.

3. The hybrid powertrain of claim **1**, wherein the first and second electric motor/generators are characterized by substantially identical input voltage and input current requirements.

4. The hybrid powertrain of claim **1**, wherein the first and second electric motor/generators are characterized by different maximum torque and power outputs.

5. The hybrid powertrain of claim **1**, wherein the first and second electric motor/generators are characterized by different torque and power outputs for maximum efficiency.

6. The hybrid powertrain of claim **1**, further comprising:

an energy storage device operatively connected to each of said first and second motor/generators for providing power to and receiving power from said first and second motor/generators, wherein said energy storage device is configured to be operatively connectable with an off-board power supply for recharging said energy storage device.

7. The hybrid powertrain of claim **1**, wherein the multiple operating modes include an engine-only operating mode.

8. The hybrid powertrain of claim **1**, wherein the multiple operating modes include an operating mode in which the engine is on and only one of the first and second electric motor/generators acts as a motor to provide torque at the output member.

9. The hybrid powertrain of claim **1**, wherein the multiple operating modes include an operating mode in which the engine is on and provides torque at the output member and both of the first and second electric motor/generators act as motors to provide torque at the output member.

10. A hybrid powertrain comprising:

an input member;

an output member;

an engine operatively connected with the input member;

first and second electric motor/generators;

a differential gear set having multiple members;

selectively engageable torque-transmitting mechanisms; wherein at least some of the input member, the output member, the engine and the motor/generators are selectively interconnected through the differential gear set by engagement of different combinations of the torque-transmitting mechanisms;

a stationary member;

wherein the multiple members include a first, a second, and a third member; wherein the first electric motor/generator is continuously connected with said first member;

wherein a first of the torque-transmitting mechanisms is selectively engageable to connect the input member to the second motor/generator; wherein a third of the torque-transmitting mechanisms is selectively engageable to ground the second member to the stationary member; wherein a second of the torque-transmitting mechanisms is selectively engageable to connect the second electric motor/generator to the second member; wherein the output member is connected for common rotation with the third member;

an electronic controller operatively connected to the electric motor/generators and configured to control the electric motor/generators to provide multiple operating modes between the input member and the output member, including:

a first electric-only operating mode in which the engine is off, and one of the first and second electric motor/generators acts as a motor to provide torque at the output member while the other of the first and second electric motor/generators is able to remain substantially stationary;

a second electric-only operating mode in which the engine is off and both first and second electric motor/generators act as motors to provide torque at the output member;

an output-split operating mode in which the first and third torque-transmitting mechanisms are engaged, the engine is on, and only the first electric motor/generator acts as a motor; and a series operating mode in which the first and second torque-transmitting mechanisms are engaged, the engine is on, and the second electric motor/generator acts as a generator to power the first electric motor/generator which acts as a motor.

11. The hybrid powertrain of claim **10**, wherein the first and second electric motor/generators are characterized by substantially identical maximum torque and power output.

12. The hybrid powertrain of claim **10**, wherein the first and second electric motor/generators are characterized by substantially identical input voltage and input current requirements.

13. The hybrid powertrain of claim **10**, wherein the first and second electric motor/generators are characterized by different maximum torque and power outputs.

14. The hybrid powertrain of claim **10**, wherein the first and second electric motor/generators are characterized by different torque and power outputs for maximum efficiency.

15. The hybrid powertrain of claim **10**, wherein the multiple operating modes include an engine-only operating mode.

16. The hybrid powertrain of claim **10**, wherein the multiple operating modes include an operating mode in which the engine is on and provides torque at the output member and both of the first and second electric motor/generators act as motors to provide torque at the output member.

17. The hybrid powertrain of claim **10**, wherein the engine is not continuously connected to any of the members of the differential gear set and is selectively connectable for common rotation with the second motor/generator by engagement of one of the torque-transmitting mechanisms.

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